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Short communication

Multi channel voltage control for fuel cells

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Abstract

Cell voltage control is a safe method to evaluate the operation of the single cells even though large efforts are being made to stabilise the behaviour of the fuel cells over the whole operating range. For fully developed systems only voltage control of single cells is necessary, whereas in test benches it is necessary to record data of the voltages during operation. Normally, a lot of cells are combined to a stack so that higher total voltages can be reached. Higher voltages make possible a high efficient transformation from direct current of the stack to alternate current of the public network. Sometimes more than 100 cells are connected together whereby the open circuit voltage of a single cell amounts to approximately 1 V. Therefore, the signal processing chips show a high supply maximum rating or the resolution of the values has to be reduced.

This paper presents an economically priced multi channel voltage control for single cells of a PEM-fuel cell in combination with a microprocessor control and was developed at the Chair for Electric Power Networks and Renewable Energy Sources. The developed system can transfer the data of up to 32 single cells in serial connection. The resolution amounts to 10 bits per channel. The module has its own microprocessor, which is responsible for the intermediate storage of the collected data and the transfer to the RS-232 interface. Optionally, the module can be equipped with an LCD-display of 20 × 4 letters where different menus of the measured and calculated values can be indicated. The module is designed for a voltage of 1 V per channel and can be supplied with a direct voltage of between 6 and 24 V from the fuel cell stack.

Keywords: Data acquisition; Fuel cell; Serial interface; Voltage control

1. Introduction

The safe operation of fuel cell prototypes and more complex field trial facilities based on fuel cell technology without an extensive control cannot normally be guaranteed. Very often it is, for example, essential to measure the single cell voltages during the operation of the fuel cell stack to prevent damage of either the single cells or the whole stack.

As a rule, commercially available systems for single voltage measurement offer a functional range, which is much larger than really needed for a simple voltage control. The systems based on measurement boards or programmable logic controller-assemblies normally cost several thousand euros. Furthermore, these solutions require a lot of space and are difficult to install.

This paper presents the concept and prototype of a voltage control mainly used for the control of PEM-fuel cell stacks. The monitoring system is characterised by a minimised material usage and limited investment costs as well as an ease of assembly.

2. Problem description

The current–voltage characteristic of a PEM-fuel cell can be subdivided into three characteristic areas. The first area is

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Nomenclature

U_{rev}	reversible cell potential
U_0	open circuit potential
η_{ohm}	voltage loss due to ohmic resistance

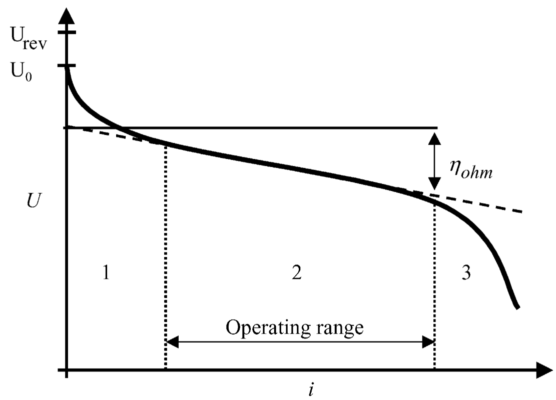

Fig. 1. Current–voltage characteristic of a PEM-fuel cell.

characterised by a voltage drop caused by activation losses (1). The second area is mainly influenced by ohmic losses of the membrane and contact resistances (2). This area shows a nearly linear dependence of the voltage on the current because the existing losses are almost constant [1]. The third voltage decrease is mainly influenced by the limited transport of the reactants to the reaction zones of the electrodes (3) (Fig. 1).

Stack design and tolerances of the produced stacks and different operating parameters like high air utilisation and reduced pressure differences can lead to different characteristics of the single cells.

Fig. 2 shows, for example, the different voltage behaviour of the single cells of an investigated fuel cell stacks at a defined operating point.

Especially, small stoichiometry numbers can lead to an undersupply of single cells with process gases. The undersupply can result in a collapse of the cell voltage and possible irreversible cell damage. Monitoring the cell voltages is, therefore, necessary to prevent a sliding of single cells. Monitoring just the stack voltage is normally not sufficient

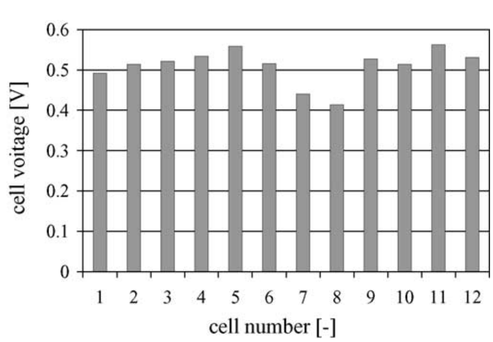

Fig. 2. Simultaneous measured voltages of the cells of a PEM-fuel cell stack.

since the voltage decrease of single cells cannot be detected if stacks with a higher number of cells are used.

Besides monitoring the cell voltages conclusions can be made in combination with other parameters if the actual voltage of the cells is known. Conclusions can also be drawn about the long-run behaviour, the gas supply or the humidity balance of the single cells.

In theory, the cell voltage amount is 1.23 V under standard conditions. In practice, however, the reachable open circuit voltage has a value of about 0.98 V.

Under maximum load this voltage decreases to approximately half of the open circuit voltage as shown in Fig. 2. Normally, a number of single cells are combined in serial connection since an effective use of the generated electrical power is only possible under considerably higher total voltages. Fuel cell stacks with about 180 cells are not unusual.

Such a stack normally provides a voltage of approximately 90 V to the consumer at maximum load. The operating dc voltage of 90 V is much lower than the voltage of the power grid so that an additional dc/dc converter is necessary beside the installation of a sinus inverter. Normally, these converters have a higher electrical efficiency at higher input voltages since the system is operated at lower currents at adequate power so that the ohmic and switching losses decrease.

With increasing cell number the complexity of the monitoring system for the single cell voltages also increases. The resulting large number of measuring points leads to higher investment cost and increased required space. Furthermore, the operating range of the signal processing unit is limited to 40 V so that this unit is not able to directly measure the cell voltages.

3. Solution to the problem

The acquisition of the cell voltages can be made in principle by measuring the voltage of each single cell or by recording the cumulated cell voltage. The cumulated measurement means the acquisition of the voltage between the single cells related to the anode potential.

A differential input of the necessary data acquisition equipment has to be used for the direct measurement of each cell voltage in order to reduce the number of channels of the most commercially available electronic devices by half. As a result, twice as many electronic devices are necessary. For measuring the cumulated cell voltage, only a single input for each cell is needed. Table 1 shows the advantages and disadvantages of both solutions.

There are a lot of possible concepts for the practical realisation of such a proposed device. Most solutions use a measurement point switcher. The digitalisation is effected with a reduced number of channels or, in the extreme case, with one channel. A disadvantage of this solution is a necessary analog signal processing in front of the AD-converter, which can be influenced by the parameters of several components of the device [2]. A simple solution can be realised with changeover

Table 1
Possible methods of resolution for single cell voltage measurement

Principle	Direct voltage measurement	Cumulated voltage measurement
Advantage	Direct measurement result, low resolution is possible	Low complexity
Disadvantage	Voltage difference measurement with higher complexity	Result only after calculation, larger resolution is necessary

switches based on relay technology. The use of such relays also guarantees a galvanic separation of the single measurement channels. A big disadvantage of this solution lies in the limited operating cycle of the relays. The lifetime of the relays is limited by their number of operations. This limit will be already reached after a half year because at a switching frequency of 1 Hz 14 Mio switching cycles has to be passed through. So, only special and expensive relays can be used to fulfill the requirements in lifetime and switching frequency if, for example, 30 cells shall be sampled within a second.

Beside the use of relays, it is also possible to install an AD-converter per cell with a direct connection to the cell. Additionally, the AD-converter with its peripheral components like reference voltage and voltage supply as well as the data acquisition has to be divided for each cell in galvanic separated assemblies to prevent dangerous overvoltages. This Version is characterised by high cost and high need of space.

Table 2 presents the different kinds of voltage acquisitions with their main advantages and disadvantages.

As a conclusion to above, the best solution concerning technical effort and cost is a combination of electronic switchers and a direct voltage measurement by AD-converter [3,4]. According to the proposed approach, a circuit for a modular assembly with potential separation was designed which can acquire the voltage values of 32 cells (Fig. 3). The limitation to 32 cells guarantees the safe operation of the electronic equipment since the system works with voltages lower than 40 V. The components, which are necessary for the design of the device like multiplexers (MUX), differential amplifier (amplifier) and the microprocessor (CPU), are standard devices offered by diverse manufacturers.

The single voltages are transferred from a 37-pole connector to four multiplexers.

The multiplexers that are controlled by a micro controller alternately switch the signals from the cell connectors to the negative and positive input of the differential amplifier. The formed voltage signal, which corresponds to the respective cell voltage, is directly transferred to the AD-input of the micro controller. In the micro controller the transferred values are assigned to the corresponding cell numbers. Furthermore, for the smoothing of the signals mean values are calculated. The three acquired minimum values with the corresponding cell numbers are directly displayed. The total voltage is measured in a separated path and can be used for the plausibility check by comparing the total voltage and the cumulated single cell voltages. The measured and calculated values are continuously actualised in the storage of the controller. The sample rate for all 32 cells amounts to approximately 10 Hz. This sample rate is limited by the switching frequency of the used multiplexers, the conversion rate of the AD-converter and the preparation of the measurement values by the microprocessor software. The display of the measured values is organised by the micro controller and is actualised each second. At the beginning of the measurement the number of cells has to be set by the buttons of the monitoring system. During the measurement the display can be switched over since the 20×4 display cannot simultaneously present all values. The measured and evaluated data can be recalled by the superordinated control via the installed RS-232 interface. One challenge was the design of an integrated power supply since a wide voltage range of $U_{in} = 5$–26 V was required. Furthermore, the supply of the circuit has to provide different voltages and has to have a potential separation.

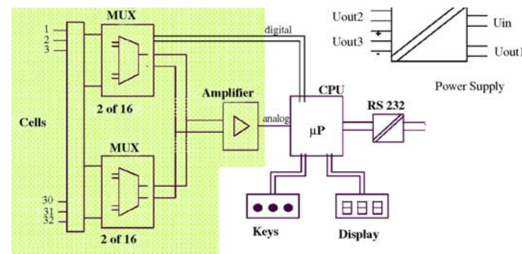

Fig. 3. Block diagram of the realised device.

This task could be solved by a self-developed switching power supply.

4. Functional model

Fig. 4 shows the functional model of the realised device as well as the most important technical data. The developed device was integrated in the PEM-fuel cell test bench installed in the laboratory of the authors. The system has been working

Table 2
Advantages and disadvantages of the possible voltage acquisition systems

Form	Switching by relays	Switching by semiconductors	Direct measurement by AD-converters
Advantage	Ease of galvanic separation, very simple construction	Unlimited switching cycles, simple construction	Each value in digital form
Disadvantage	Limited switching cycle	Galvanic separation is necessary	Requires a large space, expensive

Fig. 4. Developed voltage control with technical data. Number of measuring points = 32; voltage range = 0–1024 V; resolution = 10 bit; sample rate = ca. 10 Hz for all 32 cells; interface = RS-232; supply voltage = 4–26 V_{dc}; minima = $3U_{min}$ with cell number; moving mean = 4 values.

error-free for a time period of several months. At present, some devices are being tested at a few of our research and industrial partners in the scope of a small field trial.

5. Demonstration software

In combination with the developed hardware, demonstration software for the easy handling and fast presentation of the measurement data on a PC was programmed. This software supports the presentation of the measurement values in different ways and different windows. Besides visualisation, data acquisition and storage for a subsequent evaluation have been realised.

The software also displays the communication between the developed voltage control and the connected PC. This visualisation can be very useful for the control of the communication process and for trouble shooting.

The developed program is a run-time Version programmed with the graphical programming environment LabView®.

6. Conclusion and prospect

With the realisation of a compact single cell voltage monitoring system a capable device with a high degree of intelligence, small system size and a minimised material usage was developed. The micro controller undertakes the preprocessing in addition to the data acquisition and disburdens thereby the system control. The integrated display is especially useful for test tasks. Optionally, the communication can be exclusively realised via the system control or the PC. The device can be operated near the stack because of its very compact construction so that the wiring can be minimised. It is also imaginable to integrate a similar device in the stack. The modular design makes it possible to connect three other modules in master–slave operation and therewith a control of 128 cells. Thereby, the higher-level control communicates with the other modules only via one interface. The parallel acquisition and processing of the measurement signals is internally realised so that high sampling rates are reached. Devices with other interfaces are planned.

References

[1] J. Larminie, A. Dicks, Fuel Cell Systems—Explained, Wiley-VCH GmbH, Weinheim, 2000.
[2] R. Lacy, Measuring Cell Voltages of a Fuel Cell Stack, WO 01/14898 A1, 2001.
[3] Schalt & Regeltechnik GmbH, Datasheet, Einzel-Zellspannugs-Multiplexer EZM_48Z_24, Berlin, 2003.
[4] Smart Electronic Development GmbH, Datasheet, CVMpro60-R3, Stuttgart, 2003.